National Weather Service Reference Evapotranspiration Forecast

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Overview

While the California Irrigation Management Information System provides excellent information on near-real time reference evapotranspiration (ETo), it does not provide forecast ETo, which is useful for planning irrigation especially for high frequency irrigation systems and shallow rooted vegetation (e.g. drip systems and sprinkler irrigated turfgrass). To overcome this deficiency, the University of California and California Department of Water Resources cooperated with the Sacramento Office of the National Weather Service (NWS) to produce a forecast of ETo, which is disseminated to the public via the Internet. The ETo is estimated using the American Society of Civil Engineers – Environmental Water Resources Institute standardized ETo method (Allen et al., 2005). The calculation method is not the same as the Pruitt-Doorenbos (1977) method used in CIMIS (Snyder and Pruitt, 1992), but the daily ET_o estimates are nearly identical in most regions of the State. Daily NWS forecast data (cloud cover, maximum and minimum temperature, mean dew point temperature, and mean wind speed) are used to compute ETo for up to 7 days (the current date plus a 6-day forecast). Note that near-real time ETo from CIMIS is only available up through the day preceding the current date. Solar radiation is estimated from the ratio of actual to potential sunshine hours (n/N), which is estimated from the forecast cloud cover (C_C) following the procedures in Doorenbos and Pruitt (1977). A sample of the current date forecast on January 26, 2010 is provided (Fig. 1) for the Sacramento NWS forecast area. Note that the seven forecast maps are displayed by clicking on the day 1, day 2, etc. above the map, where day 1 is the current date. The ETo forecast product has been available from the Sacramento NWS Office for several months and other NWS Offices are in the process of adding this product.

ETo Calculations

The steps needed to estimate reference evapotranspiration (ETo) follow in the same sequence as the computer code. Calculations are done for locations with NWS forecasts, and an ETo map is generated from the spatial data. Site characteristics include the latitude and elevation (E_L) in meters above sea level. The required weather data includes the percentage cloud cover (C_C), maximum (T_x) and minimum (T_n) air temperature in $^{\circ}$C, mean wind speed in m s^{-1}, and mean dew point (T_d) temperature in $^{\circ}$C. The wind speed was adjusted from the standard NWS 10 m height to 2.0 m height using:

$$u_2 = u_z \left(\frac{4.87}{\ln(67.8 z_w - 5.42)} \right)$$

where u_z = wind speed (m s^{-1}) at height z_w (m) above the ground.

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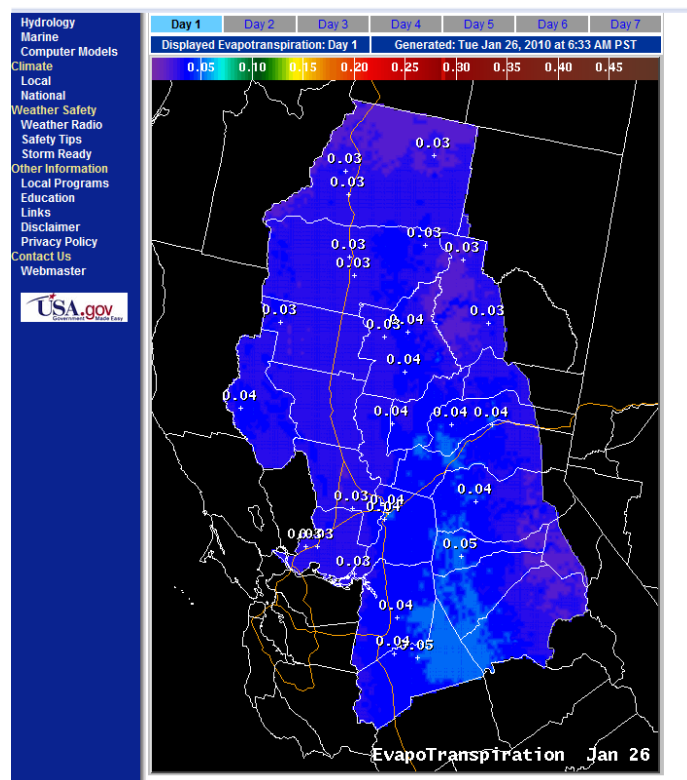[4] State Climatologist, Calif. Dept. of Water Res., P.O. Box 942836, Sacramento, CA 94236-0001

Figure 1. A sample ETo forecast map for the Sacramento NWS forecast area on January 26, 2010.

ETo Calculations

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STEP 1: Extraterrestrial radiation (R_a) is calculated for each day using the following equations from Duffie and Beckman (1980).

G_{SC} = solar constant in MJ m^{-2} min^{-1}
    $G_{SC} = 0.082$
σ = Steffan-Boltzman constant in MJ m^{-2} d^{-1} K^{-4}
    $\sigma = 4.90 \times 10^{-9}$
ϕ = latitude in radians converted from latitude (L) in degrees

$$\phi = \frac{\pi L}{180}$$

d_r = correction for eccentricity of Earth's orbit around the sun on day i of the year

$$d_r = 1 + 0.033 \cos\left(\frac{2\pi}{365} i\right) \tag{1}$$

δ = declination of the sun above the celestial equator in radians on day i of the year

$$\delta = 0.409 \sin\left(\frac{2\pi}{365} i - 1.39\right) \tag{2}$$

ω_s = sunrise hour angle in radians

$$\omega_s = \cos^{-1}\left[-\tan\phi \tan\delta\right] \tag{3}$$

R_a = extraterrestrial radiation (MJ m^{-2} d^{-1})

$$R_a = \left(\frac{24 \cdot 60}{\pi}\right) G_{SC} d_r \left[\omega_s \sin\delta \sin\phi + \cos\phi \cos\delta \sin\omega_s\right] \tag{4}$$

STEP 2: Calculate the daily net radiation (R_n) expected over grass in MJ m^{-2} d^{-1} using equations from Allen et al. (1994).

R_{so} = clear sky total global solar radiation at the Earth's surface in MJ m^{-2} d^{-1}

$$R_{so} = R_a\left(0.75 + 2.0 \times 10^{-5} E_L\right) \tag{5}$$

n/N = potential sunshine hours estimated from cloud cover (C_C) percentage –based on data from Doorenbos and Pruitt (1977).

$$n/N = -0.0083 \cdot C_C + 0.9659 \tag{6}$$

R_s = solar radiation estimated from potential sunshine hours (n/N) and R_a – from Doorenbos and Pruitt (1977).

$$R_s = \left(0.25 + 0.5\frac{n}{N}\right) R_a \tag{7}$$

R_{ns} = net solar radiation over grass as a function of measured solar radiation (R_S) in MJ m^{-2} d^{-1}

$$R_{ns} = (1 - 0.23) R_s \tag{8}$$

f = a cloudiness function of R_s and R_{so}

$$f = 1.35\frac{R_s}{R_{so}} - 0.35 \tag{9}$$

$e_s(T_x)$ = saturation vapor pressure (kPa) at the maximum daily air temperature (T_X) in ^{o}C

$$e_s(T_x) = 0.6108 \exp\left(\frac{17.27 T_x}{T_x + 237.3}\right) \tag{10}$$

$e_s(T_n)$ = saturation vapor pressure (kPa) at the minimum daily air temperature (T_n) in ^{o}C

$$e_s(T_n) = 0.6108 \exp\left(\frac{17.27 T_n}{T_n + 237.3}\right) \tag{11}$$

e_a = actual vapor pressure or saturation vapor pressure (kPa) at the mean dew point temperature from the daily maximum (T_x) and minimum (T_n) temperature (^{o}C) and maximum (RH_x) and minimum (RH_n) relative humidity (%).

$$e_a = \frac{\left(\dfrac{RH_x + RH_n}{2}\right)}{\left(\dfrac{50}{e_s(T_x)} + \dfrac{50}{e_s(T_n)}\right)} \tag{12}$$

e_a = actual vapor pressure or saturation vapor pressure (kPa) at the daily mean dew point (T_d) temperature.

$$e_a = 0.6108 \exp\left[\frac{17.27T_d}{T_d + 237.3}\right] \tag{13}$$

ε' = apparent 'net' clear sky emissivity

$$\varepsilon' = 0.34 - 0.14\sqrt{e_a} \tag{14}$$

Note that $\varepsilon' = \varepsilon_{vs} - \varepsilon_a$, where ε_{vs} is the emissivity of grass and ε_a is the emissivity from the atmosphere. It is called 'apparent' because the temperature from a standard shelter rather than the surface temperature and atmosphere temperature are used to calculate the 'net' long–wave radiation balance. Equation 14 is called the 'Brunt form' equation for net emittance because the form of the equation is similar to Brunt's equation for apparent long-wave emissivity from a clear sky.

R_{nl} = net long wave radiation in MJ m^{-2} d^{-1}

$$R_{nl} = -f\,\varepsilon'\,\sigma\left[\frac{(T_x + 273.15)^4 + (T_n + 273.15)^4}{2}\right] \tag{15}$$

R_n = net radiation over grass in MJ m^{-2} d^{-1}

$$R_n = R_{ns} + R_{nl} \tag{16}$$

STEP 3: Calculate variables needed to compute ET_o.

β = barometric pressure in kPa as a function of elevation (E_l) in meters

$$\beta = 101.3\left(\frac{293 - 0.0065E_l}{293}\right)^{5.26} \tag{17}$$

λ = latent heat of vaporization in (MJ kg^{-1})

$$\lambda = 2.45 \tag{18}$$

γ = psychrometric constant in kPa $^{\circ}$C^{-1}

$$\gamma = 0.00163\frac{\beta}{\lambda} \tag{19}$$

T_m = mean daily temperature in $^{\circ}$C

$$T_m = \frac{T_x + T_n}{2} \tag{20}$$

e^o = saturation vapor pressure at T_m

$$e^o = 0.6108 \exp\left(\frac{17.27T_m}{T_m + 237.3}\right) \tag{21}$$

Δ = slope of the saturation vapor pressure curve (kPa $^{\circ}$C^{-1}) at mean air temperature (T_m)

$$\Delta = \frac{4099e^o}{(T_m + 237.3)^2} \tag{22}$$

G = soil heat flux density in MJ m^{-2} d^{-1}

$$G \approx 0 \tag{23}$$

e_s = mean daily saturation vapor pressure (kPa)

$$e_s = \frac{e_s(T_x) + e_s(T_n)}{2} \tag{24}$$

STEP 4: Calculate ET_o using the ASCE-EWRI (2004) standardized equation for short canopy reference ET.

R_o = radiation term of the Penman-Monteith equation for short canopy reference ET with U_2 the wind speed at 2 m height

$$R_o = \frac{0.408\Delta(R_n - G)}{\Delta + \gamma(1 + 0.34U_2)} \tag{25}$$

where 0.408=1/2.45 converts the units from MJ m^{-2} d^{-1} to mm d^{-1}.

A_o = aerodynamic term of the Penman-Monteith equation for short canopy reference ET with u_2 the wind speed at 2 m height

$$A_o = \frac{\left(\dfrac{900\gamma}{T_M + 273}\right)U_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34U_2)} \tag{26}$$

The standardized reference evapotranspiration for a short, 0.12 m, canopy in mm d^{-1} is:

$$ET_o = R_o + A_o \tag{27}$$

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